REPORT ON POSSIBLE METHODS OF REDUCING THE SYMPTOMS PRODUCED BY RAPID CHANGE IN THE SPEED AND DIRECTION OF AIRPLANES

by

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INTRODUCTION

The results of experiments to determine the physiological effects of sudden changes in speed and direction of airplanes were reported in a previous communication. The changes studied in detail were those which experience has shown result in symptoms on the part of the occupants of the plane. These occur in manoeuvres in which an abnormal centrifugal acceleration is developed along the vertical axis of the plane, i.e., the long axis of the pilot's body. Most commonly they are found in tight horizontal turns and in sharply pulling out of a dive. These results will be described in some detail to introduce the subject of this report, viz., a possible method for alleviating the symptoms.

An abnormal centrifugal acceleration downward along the long axis of the body produces a series of changes, essentially hydrostatic, which result ultimately in impairment of cerebral circulation. There is (1) a drop in blood pressure in the arteries of the upper part of the body which

results from purely hydrostatic forces acting upon the column of blood contained in the larger arteries. This is closely followed by (2) a secondary drop in pressure which is the result of decreased heart output resulting from decreased supply of blood to the heart. The centrifugal force acting upon the column of blood in the large veins either imprisons the blood in these vessels or drives it downward away from the heart and reduces the volume delivered to the auricles. This secondary drop is the more profound, reducing the arterial pressure to a point well below that known to produce symptoms of cerebral origin. It varies with the magnitude of the acceleration and the condition of the animal. In modern manoeuvres in which the acceleration is about 4 or 5 g., the average drop is from 70 to 80 mm. Hg. In one instance in which the acceleration attained practically 6 g., the pressure in the carotid artery dropped from 135 to 16 mm. Hg in 4 seconds, a situation certain to result in loss of consciousness.

heart can reduce the volume available for delivery to the auricles. If, then, appliances can be devised to prevent this pooling and maintain the supply to the auricles, the secondary drop in arterial pressure incident to the reduced heart filling should be prevented or reduced, and this secondary drop apparently accounts for the cerebral anoxemia and the symptoms.

The practical difficulties surrounding any attempt to prevent pooling in the extremities are obvious, especially when the importance of the extremities in the control of an airplane are considered. However, the tremendous abdominal pool of blood is available for such change in distribution and pressure, and it is practicable to devise means for increasing the intraabdominal pressure without interference with muscular activity and without real distress to the aviator.

In the previous report it was pointed out that simple restraint of the abdomen by an elastic belt failed to effect a reduction of the fall in blood pressure. On the other hand, an inflatable bag held

firmly against the abdomen and which conforms to the contours and changes in volume of the abdominal cavity will exert a constant increased pressure, transmitted to the intra-abdominal vessels. This increased pressure should resist pooling more effectively than simple restraint. On this assumption a series of experiments was conducted using this increased intra-abdominal pressure as a possible impediment to pooling.

THE EXPERIMENTS

Direct records of blood pressure changes in the dog during dive bombing, etc., were obtained by the technique described in the previous report. An abdominal belt containing an inflatable rubber bag was constructed so that inflation would compress the abdomen. Preliminary experiments determined the size, shape and texture of the bag which would produce an intra-abdominal pressure equal to that in the bag. A flask containing compressed nitrogen was equipped with a reducing valve which delivered gas to the bag and maintained a minimum pressure. Records were made during varying aerial manoeuvres,

using varying pressures and applying the pressure at varying stages of the manoeuvre.

The first experiments met with failure. Postulating that increasing the intra-abdominal pressure would act as a dam to the centrifugal flood of blood into the veins below the heart, experiments were conducted in which a pressure of from 50 to 150 mm. Hg was suddenly applied to the abdomen immediately before the body was subjected to a high acceleration. When a dog was dived without any pressure against the abdomen and then taken through an identical dive but with pressure suddenly applied within a few seconds of the pull out, the resulting graphs of the carotid pressure could be practically superimposed upon each other. Obviously, simply damming the blood above the abdomen was not sufficient to prevent the secondary drop in arterial pressure.

The Time Element

In an effort to explain these findings a series of experiments was conducted in the laboratory. Records were made of the pressures in the carotid artery, the jugular vein, and the femoral artery and vein in different positions and with pressures applied to the abdomen at varying times in respect to changes in position. The results disclosed that there is a perceptible delay in the changes in blood

pressure incident to an increase in intra-abdominal pressure which is highly significant. These changes are summarized in the following generalizations:

Arterial Pressure. There is an immediate sharp rise in arterial pressure. This stimulates the carotid sinus and depressor nerves to produce a general vasodilation. The resultant drop in pressure persists for some time and the pressure does not return to normal until after several seconds.

Venous Pressure. In the femoral veins there is an immediate sharp rise of a few millimeters followed by a very gradual rise which attains a maximum of from 50 to 60 mm. above normal only after several seconds, ranging from 12 to 30 seconds in different animals.

In the jugular vein there is no immediate rise but a very gradual rise over a period of several seconds.

A possible explanation for this delay lies in the fact that the increase in venous pressure is incident to the diversion of blood from the "portal pool." This diversion can take place only by

The essential effect of the drop in arterial pressure is, then, a suspension of circulation through the brain which produces an acute, local anoxemia. All the symptoms experienced, generally grouped in the expression "going black", are explicable on the basis of this cerebral anoxemia.

PLAN OF INVESTIGATION

In searching for a means to ameliorate the symptoms attending high accelerations the following general physiological principles must be considered: The centrifugal force, acting downward through the body, tends to throw the blood contained in the large vessels into the lower parts of the body. Because of the higher pressures in the arteries this will cause a comparatively small distortion of the distribution of the blood in them, the effect being primarily a change in the pressure in the upper and lower parts of the arterial tree. In the veins the situation is complicated by the fact that the pressure is already comparatively low, being at times negative in the chest, and the venous bed below the heart is large enough to contain quantities considerably in excess of those normally present. Pooling below the

resisting the flow through the mesenteric capillaries or, more likely, by forcing it through the liver capillaries into the systemic venous circulation. Because of the resistance of these capillary systems the diversion is delayed.

Both of these factors are significant in conjecturing any improvement in the circulatory response to high accelerations by the application of pressure against the abdomen.

The effect upon the arterial pressure is in the same direction as the effect of the gravitational forces encountered in a dive and pull out. If they occur synchronously, a summation of the two is to be expected. If sufficient time is permitted to elapse between the application of abdominal pressure and the high acceleration, the first effect will have ended in a return of pressure to normal and there will be no summation.

The effect of delay upon the venous system will be an increase in the amount of blood in the systemic venous circulation at the expense of the portal system and a materially higher pressure in the inferior vena

cava. These should combine to prevent reduced cardiac filling incident to high accelerations and thus reduce the secondary drop in arterial pressure.

These changes in both the arterial and venous systems are accomplished in about thirty seconds.

A series of experiments was conducted during flying using this time factor, i.e., applying pressure to the abdomen a considerable time before the application of high acceleration. The results are apparent in the following graphs:

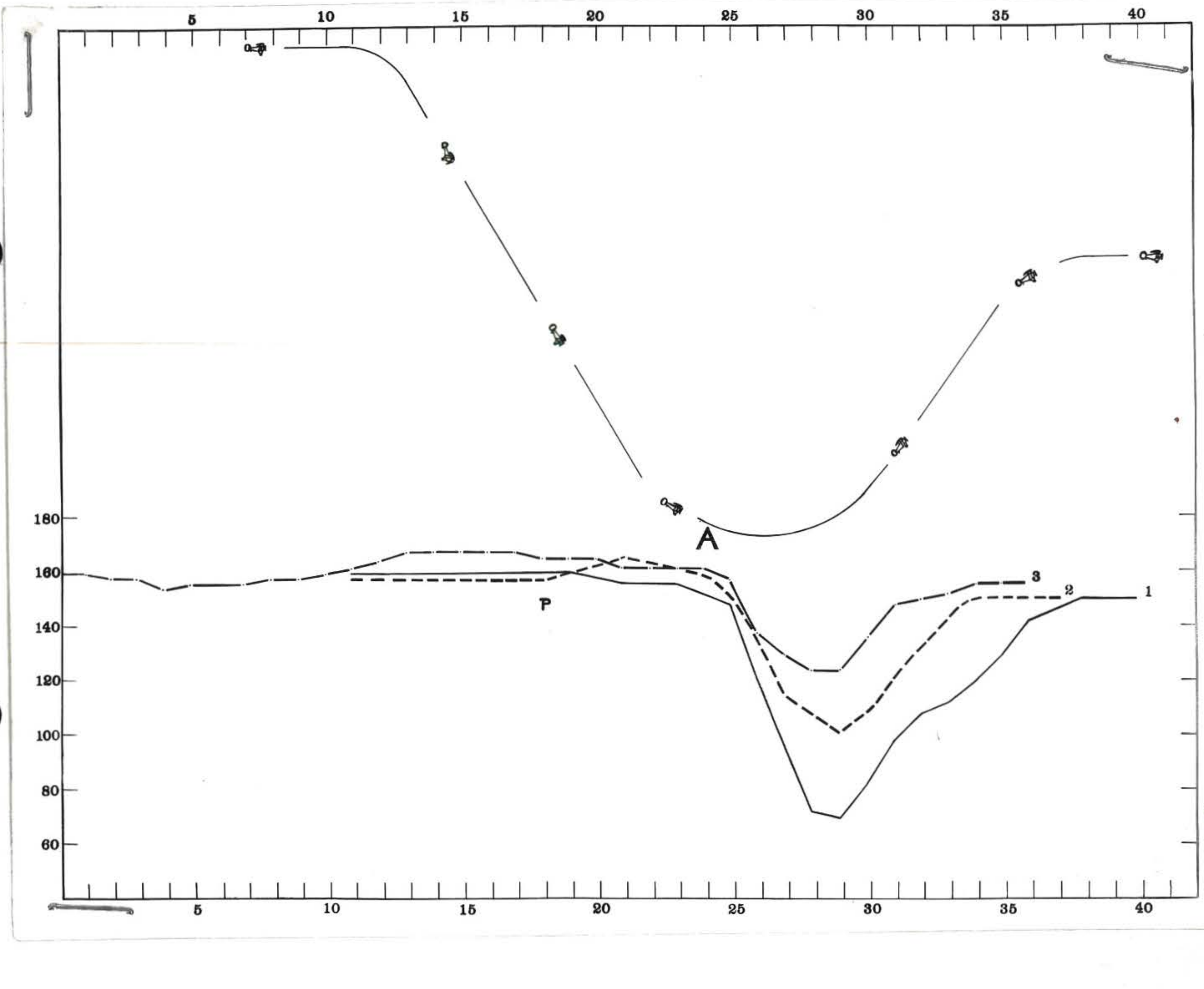

Fig. 1. The Dive.

The Dive

Figure 1 shows the changes in carotid arterial pressure in three dives, pressure of approximately 100 mm. Hg being applied against the abdomen at different times in two. The manoeuvre is indicated by the course of the plane. It dove from the 12th to the 24th second. The pull out was from the 24th to the 29th second. This is the period of high centrifugal acceleration downward along the long axis of the dog. In all three curves the acceleration, as indicated on a recording accelerometer, was 5.1 g.

In curve 1 no pressure was applied to the abdomen. In curve 2 the pressure was suddenly applied at the 18th second, P, 6 seconds before the pull out. In curve 3 the pressure had been applied 10 seconds before the beginning of the graph -- 34 seconds before the pull out.

In curve 1 the carotid pressure dropped 90 mm., to 70 mm. Hg. In curve 2 the pressure dropped 56 mm., to 102 mm. Hg. In curve 3 it dropped only 36 mm., to 124 mm., Hg. The effect of applying

pressure against the abdomen is manifest. Applied 34 seconds before experiencing an acceleration exactly equal to that encountered in a manoeuvre identical with one in which no pressure was applied, it reduced the drop in carotid pressure and kept it at a level perfectly compatible with freedom from symptoms. The effect is more significant in view of the fact that the successive dives were made at intervals of only two minutes and the cumulative effect of quickly repeated dives would have indicated a more profound drop in the third than in the first.

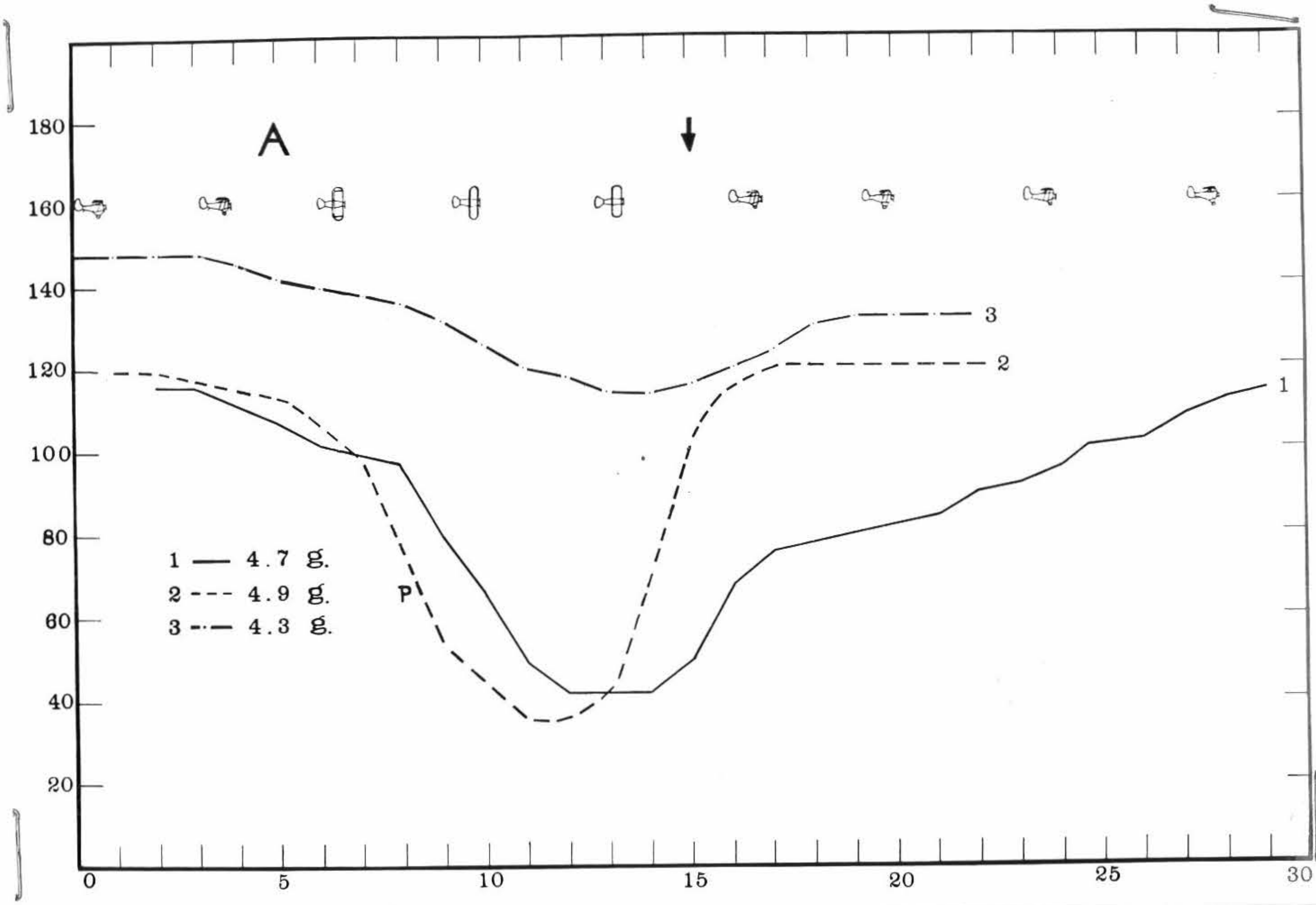

Fig. 2. The Horizontal Turn.

The Horizontal Turn

Figure 2 shows the effect of applying pressure against the abdomen in making a tight horizontal turn. The manoeuvre is indicated by the position of the plane. The turn was begun at the 5th second and lasted to include the 15th. The peak of acceleration attained in the three turns is indicated as 4.7, 4.9 and 4.3 g., respectively.

In curve 1 no pressure was applied. In curve 2 it was applied as indicated, P, during the turn, at the 8th second. In curve 3 it had been applied 2 minutes before the beginning of the graph.

In curve 1 the carotid pressure dropped 74 mm., to 42 mm. Hg. In curve 2 it dropped 80 mm., to 36 mm. Hg; and in curve 3 it dropped only 34 mm., to 114 mm. Hg. The improvement is even more striking than in the dive. Having applied pressure to the abdomen a considerable time before experiencing the high acceleration of a horizontal turn, the drop in carotid pressure is reduced and it is maintained at a comfortable level. This manoeuvre is often more distressing than the dive because the high acceleration extends over a longer time.

Femoral Pressures

Figure 3 is a composite showing the changes in the pressures in the femoral artery and vein incident

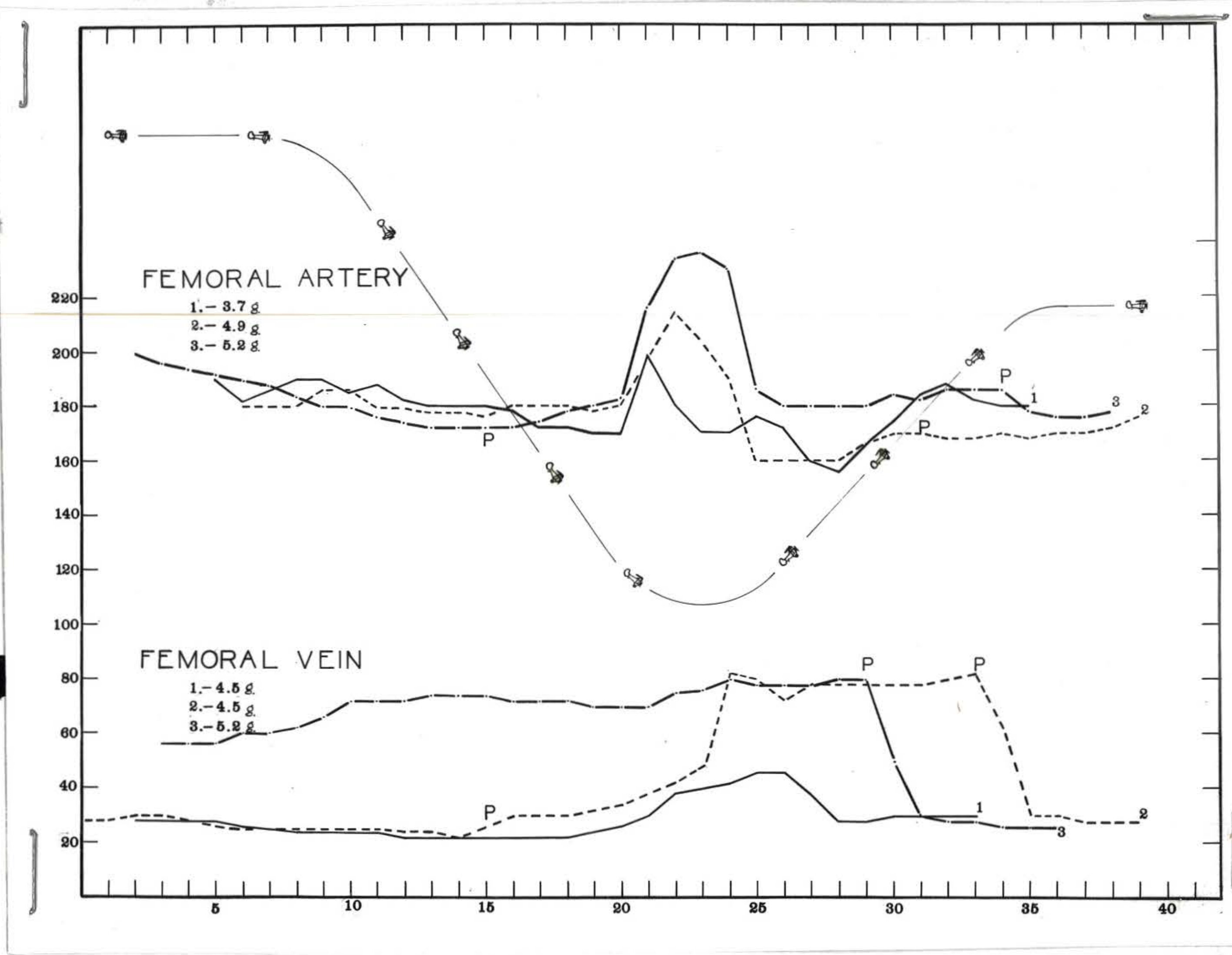

Fig. 3. Femoral Pressure.

to the dive and with pressure applied to the abdomen at different times in relation to the dive.

Arterial Pressure. The upper curves show the changes in the femoral artery. It will be noted that the pressures range higher than in the carotid artery. This difference is found in dogs in the erect posture. The manoeuvre and the order of the curves are the same as those showing carotid pressures in the dive. Curve 1 is without abdominal pressure, curve 2 is with pressure applied at P. 5 seconds before the pull out, and in curve 3 pressure had been applied 10 seconds before the graph or 30 seconds before the pull out.

In curves 1 and 2 there is a sharp rise in pressure upon the application of high acceleration, which is followed before the completion of the pull out by a drop in pressure which is a reflection of the general systemic drop in pressure. The final pressure in the femoral artery is not so low as that seen in the carotid artery, but it does represent a fall of from 40 to 50 mm. from the high produced by the centrifugal hydrostatic effect upon the lower end of the arterial column.

In curve 3, in which pressure had been applied to the abdomen 30 seconds before the pull out and the effects of this pressure had been accomplished, the pressure rises sharply and is maintained at a high level while the acceleration is in effect. There is no

drop in pressure indicating a profound general drop. If this curve is superimposed upon curve 3 in figure 1, it will be seen that practically the only result of the high acceleration is the hydrostatic change to be expected in an elastic tube subjected to the same force. The carotid artery tracings represent the top and the femoral artery tracings the bottom of the tube of blood.

Venous Pressures. The lower curves show the changes in the femoral vein. The order of applying pressure was the same as for the arterial curves. In curve 1 there was a comparatively slow rise in pressure of only about 20 mm. Curves 2 and 3 show the delay in the rise of venous pressure incident to the application of pressure against the abdomen described on page 5. In curve 2 the pressure rose slowly from the 15th to the 23rd second when it was given an abrupt thrust upward by the high acceleration. The notch at the 26th second indicates the point at which this acceleration effect met the gradual abdominal pressure effect begun at the 15th second. In curve 3 the rise due to abdominal pressure is still noticeable at the beginning of the curve. The high level is not attained until the 10th second, which is 20 seconds after the application of the pressure. From the 8th to the 20th second the plane was diving and gravity was essentially zero as compared to 1 g. before this time. The hydrostatic force would tend to lower the pressure in

the femoral vein during this time but, in fact, the pressure continued to rise in spite of this. The rise at the application of high acceleration is insignificant.

The Amount of Pressure

A series of experiments was conducted to determine the effect of varying amounts of pressure against the abdomen. Dogs were dived at the same acceleration, about 4.5 g., with pressure against the abdomen beginning with 20 mm. and increasing by increments of 20 mm. The resulting reduction in the drop in carotid pressure follows a logarithmic curve, with rapidly increasing improvement from pressures above 80 mm. Hg.

It is felt that these results are somewhat misleading. Subjectively it has been found that a pressure of 50 mm. causes a marked amelioration of symptoms, even those attending rapidly repeated manoeuvres of considerable acceleration. With the type of belt used in the preliminary experiments on men, pressures of 100 mm. and more are attended by some distress. With abdominal movement restricted, respiration becomes necessarily entirely thoracic. To the uninitiated this appears as a restriction in breathing, particularly if the belt embraces the lower ribs. A more comfortably designed belt should eliminate these subjective manifestations of distress. A compromise between the amounts of pressure which can be borne without distress, and relief from the

symptoms of high acceleration, should be found as a result of trial by a large number of pilots under varying pressures and accelerations. Because of the variation in individual susceptibility and vasomotor efficiency, it may be found that the amount of pressure should be controllable by the individual to meet his own needs.

The Belt

The belt should be made of inelastic fabric. It should cover the entire abdomen, extend well down over the symphysis and as high over the epigastrium as can be held in position without restricting the lower ribs. It should be held in position by a belt and straps which extend around the back so that inflation of the contained bag will produce no bulging outward. The projection over the lower abdomen should be held in close apposition to symphysis by perineal straps. Comfort and freedom of movement should be preserved as far as possible.

The inflatable bag should embrace the entire abdomen extending well into the flanks. Expansion should be uniform over the entire area. It should be sufficiently pliable so that the contained pressure will not be absorbed by the elasticity of the bag but will be transmitted into the abdomen. The source of air supply and the control, being entirely dependent upon availability of sources of energy and adaptability to aircraft, is a problem appropriately coming within the purview of an aeronautical laboratory.

CONCLUSIONS

The investigations reported have definitely established the fact that raising the intra-abdominal pressure by means of an inflatable bag held firmly against the abdomen by an inelastic belt causes a reduction of physiological changes responsible for the symptoms incident to rapid changes in speed and direction of airplanes. It eliminates the secondary drop in arterial pressure which causes the cerebral anoxemia. The results leave no doubt that the application of pressure against the abdomen at least one-half minute in advance of anticipated high accelerations will relieve the symptoms experienced in manoeuvres in which these accelerations develop.

A few preliminary flights have been made using more or less improvised belts and sources of air supply. Without exception the results have indicated an almost complete relief from the distress attending high accelerations. The application of pressures as low as 50 mm. well in advance of the anticipated acceleration -- at least 30 seconds -- has unmistakably relieved the customary symptoms.

SUMMARY

Anesthetized dogs were mounted in an airplane in a position exactly similar to that occupied by an aviator, and were subjected to rapid horizontal turns and dives. Direct records of pressures in the carotid artery, the

jugular vein, and the femoral artery and vein were made during these manoeuvres.

A belt embracing the entire abdomen and containing an inflatable bag was strapped about the dog. Inflation of this bag produced an increase in intra-abdominal pressure. This was done at different times in relation to the manoeuvres.

Raising the intra-abdominal pressure shortly before the high accelerations of the manoeuvre produced no material improvement in the physiological changes incident to these high accelerations.

Raising the intra-abdominal pressure by inflation of the belt at least one-half minute before the high accelerations produced a marked improvement in the physiological changes. The improvement was a preservation of carotid cerebral circulation at a level above that resulting in severe anoxemia and consistent with freedom from subjective symptoms.

Raising the intra-abdominal pressure by the inflation of such a belt at least one-half minute before subjection to high accelerations should relieve an aviator of the symptoms experienced as a result of these accelerations.

Preliminary trials on aviators using a crude type of belt have produced results completely justifying this last conclusion.